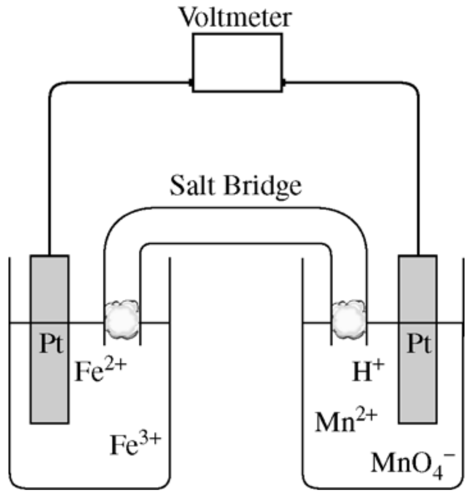
Question 2
(10 points)



$$5\ Fe^{2+}(aq) + MnO_4^-(aq) + 8\ H^+(aq) \rightarrow 5\ Fe^{3+}(aq) + Mn^{2+}(aq) + 4\ H_2O(l)$$

A galvanic cell and the balanced equation for the spontaneous cell reaction are shown above. The two reduction half-reactions for the overall reaction that occurs in the cell are shown in the table below.

Half-Reaction	$E°$ (V) at 298 K
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+ 0.77
$MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^- \rightarrow Mn^{2+}(aq) + 4\ H_2O(l)$	+1.49

(a) On the diagram, clearly label the cathode.

The electrode in the beaker on the right should be labeled.	One point is earned for correct identification of the cathode.

(b) Calculate the value of the standard potential, $E°$, for the spontaneous cell reaction.

$E_{cell} = 1.49 - 0.77 = 0.72$ V	One point is earned for the correct numerical answer.

(c) How many moles of electrons are transferred when 1.0 mol of $MnO_4^-(aq)$ is consumed in the overall cell reaction?

5.0 moles of electrons are transferred.	One point is earned for the correct numerical answer.

Question 2 (continued)

(d) Calculate the value of the equilibrium constant, K_{eq}, for the cell reaction at 25°C. Explain what the magnitude of K_{eq} tells you about the extent of the reaction.

$\log K_{eq} = \dfrac{nE}{0.0592} = \dfrac{5 \times 0.72}{0.0592} = 61$ $K_{eq} = 6.5 \times 10^{60}$ Because the magnitude of K_{eq} is very large, the extent of the cell reaction is also very large and the reaction goes essentially to completion.	One point is earned for the correct substitution. One point is earned for the correct numerical answer. One point is earned for an explanation.

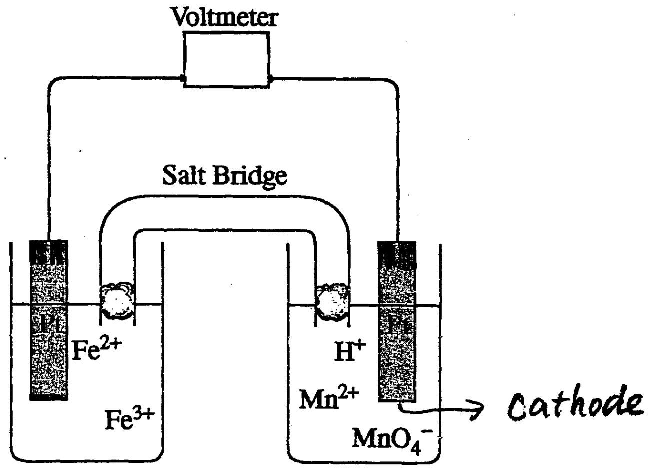
Three solutions, one containing $Fe^{2+}(aq)$, one containing $MnO_4^-(aq)$, and one containing $H^+(aq)$, are mixed in a beaker and allowed to react. The initial concentrations of the species in the mixture are 0.60 M $Fe^{2+}(aq)$, 0.10 M $MnO_4^-(aq)$, and 1.0 M $H^+(aq)$.

(e) When the reaction mixture has come to equilibrium, which species has the higher concentration, $Mn^{2+}(aq)$ or $MnO_4^-(aq)$? Explain.

$[Mn^{2+}(aq)]$ will be greater than $[MnO_4^-(aq)]$ because: (1) as indicated in part (d), the reaction essentially goes to completion, and (2) there is more than sufficient Fe^{2+} and H^+ to react completely with the MnO_4^-. $[MnO_4^-(aq)]$ at equilibrium is essentially zero.	One point is earned for the choice of Mn^{2+} with the explanation including only item (1). One point is earned for including item (2) in the explanation.

(f) When the reaction mixture has come to equilibrium, what are the molar concentrations of $Fe^{2+}(aq)$ and $Fe^{3+}(aq)$?

At equilibrium, $[Fe^{2+}(aq)] = [Fe^{2+}(aq)]_{initial} - 5[MnO_4^-(aq)]_{reacted}$ $= 0.60 - 5(0.10) = 0.10\ M$ $[Fe^{3+}(aq)] = 5 \times [MnO_4^-(aq)]_{reacted}$ $= 5\,(0.10) = 0.50\ M$	One point is earned for a correct setup (including a correct setup for an equilibrium calculation). One point is earned for correct numerical answers.



$$5\,Fe^{2+}(aq) + MnO_4^-(aq) + 8\,H^+(aq) \rightarrow 5\,Fe^{3+}(aq) + Mn^{2+}(aq) + 4\,H_2O(l)$$

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2. A galvanic cell and the balanced equation for the spontaneous cell reaction are shown above. The two reduction half-reactions for the overall reaction that occurs in the cell are shown in the table below.

Half-Reaction	$E°$ (V) at 298 K
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.77
$MnO_4^-(aq) + 8\,H^+(aq) + 5\,e^- \rightarrow Mn^{2+}(aq) + 4\,H_2O(l)$	+1.49

(a) On the diagram, clearly label the cathode.

(b) Calculate the value of the standard potential, $E°$, for the spontaneous cell reaction.

(c) How many moles of electrons are transferred when 1.0 mol of $MnO_4^-(aq)$ is consumed in the overall cell reaction?

(d) Calculate the value of the equilibrium constant, K_{eq}, for the cell reaction at 25°C. Explain what the magnitude of K_{eq} tells you about the extent of the reaction.

Three solutions, one containing $Fe^{2+}(aq)$, one containing $MnO_4^-(aq)$, and one containing $H^+(aq)$, are mixed in a beaker and allowed to react. The initial concentrations of the species in the mixture are 0.60 M $Fe^{2+}(aq)$, 0.10 M $MnO_4^-(aq)$, and 1.0 M $H^+(aq)$.

(e) When the reaction mixture has come to equilibrium, which species has the higher concentration, $Mn^{2+}(aq)$ or $MnO_4^-(aq)$? Explain.

(f) When the reaction mixture has come to equilibrium, what are the molar concentrations of $Fe^{2+}(aq)$ and $Fe^{3+}(aq)$?

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2A2

2.(b) $E^\circ = E^\circ_{cathode} - E^\circ_{anode} = 1.49V - 0.77V = 0.72V$

(c) moles of electrons = $(1\ mol\ MnO_4^-)\left(\frac{5\ mol\ e^-}{1\ mol\ MnO_4^-}\right) = 5$ moles

(d) $\log K = \frac{nE^\circ}{0.0592} = \frac{5 \times (0.72V)}{0.0592} = 60.81$

$K_{eq} = 10^{60.81} = 6.46 \times 10^{60} >> 1.$

Thus, the extent of reaction is very large, meaning the reaction proceeds forward nearly completely.

(e) For 0.10 M $MnO_4^-(aq)$

~~The~~ molar Fe^{2+} needed $= (0.10M\ MnO_4^-)\left(\frac{5\ mol\ Fe^{2+}}{1\ mol\ MnO_4^-}\right) = 0.50 M\ Fe^{2+} < 0.60 M\ Fe^{2+}$

Molar H^+ needed $= (0.1M\ MnO_4^-)\left(\frac{8\ mol\ H^+}{1\ mol\ MnO_4^-}\right) = 0.8 M\ H^+ < 1.0 M\ H^+$

Thus, the limiting reactant is MnO_4^-

Because the reaction proceeds forward nearly completely ~~the~~, nearly ~~all of~~ MnO_4^- is converted into Mn^{2+}. Thus $Mn^{2+}(aq)$ has higher concentration than MnO_4^-.

(f) $5Fe^{2+}(aq) + MnO_4^-(aq) + 8H^+ \rightarrow 5Fe^{3+}(aq) + Mn^{2+}(aq) + 4H_2O(l)$

initial 0.6 M 0.10M 0

ΔM −5x −x +5x

equilibrium 0.6−5x 0.1−x 5x

Since $K_{eq} >> 1$ $0.1-x \simeq 0$ $x \simeq 0.1$

$[Fe^{2+}] = 0.6 - 0.5 = 0.1 M$ $[Fe^{3+}] = 5x = 0.5 M$

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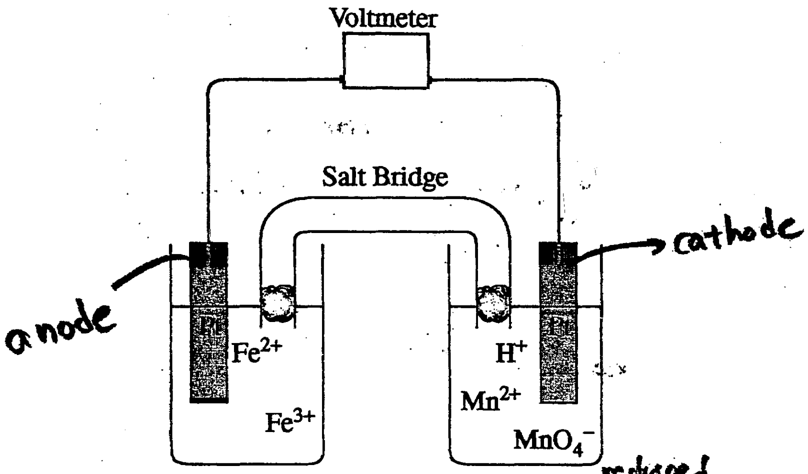
2B1



$$5\,Fe^{2+}(aq) + MnO_4^-(aq) + 8\,H^+(aq) \rightarrow 5\,Fe^{3+}(aq) + Mn^{2+}(aq) + 4\,H_2O(l)$$

oxidized

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$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.77
$MnO_4^-(aq) + 8\,H^+(aq) + 5\,e^- \rightarrow Mn^{2+}(aq) + 4\,H_2O(l)$	+1.49

(a) On the diagram, clearly label the cathode.

(b) Calculate the value of the standard potential, $E°$, for the spontaneous cell reaction.

(c) How many moles of electrons are transferred when 1.0 mol of $MnO_4^-(aq)$ is consumed in the overall cell reaction?

(d) Calculate the value of the equilibrium constant, K_{eq}, for the cell reaction at 25°C. Explain wnat the magnitude of K_{eq} tells you about the extent of the reaction.

Three solutions, one containing $Fe^{2+}(aq)$, one containing $MnO_4^-(aq)$, and one containing $H^+(aq)$, are mixed in a beaker and allowed to react. The initial concentrations of the species in the mixture are 0.60 M $Fe^{2+}(aq)$, 0.10 M $MnO_4^-(aq)$, and 1.0 M $H^+(aq)$.

(e) When the reaction mixture has come to equilibrium, which species has the higher concentration, $Mn^{2+}(aq)$ or $MnO_4^-(aq)$? Explain.

(f) When the reaction mixture has come to equilibrium, what are the molar concentrations of $Fe^{2+}(aq)$ and $Fe^{3+}(aq)$?

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2B$_2$

(a) On the diagram, the cathode is the side with permanganate ion (MnO_4^-)

(b) $E° = E°_{cathode} - E°_{anode}$

$= 1.49\ V - 0.77\ V = 0.72\ V$

(c)

For every MnO_4^- that is reduced to Mn^{2+}, five electrons are transferred.

Therefore, moles of electrons transferred =

$5 \times 1.0\ mol = 5.0\ mol$

(d) At equilibrium $E° = \frac{0.0592}{n} \log K_{eq}$ at $25°C$

$\log K_{eq} = \frac{5 \times 0.72}{0.0592} = 60.8108$

$K_{eq} = 6.47 \times 10^{60}$

This value of K_{eq} indicates that a lot of products will be produced from the reaction, more than leftover reactants

(e). $5Fe^{2+} + MnO_4^- + 8H^+ \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$

	$5Fe^{2+}$	MnO_4^-	$8H^+$	$5Fe^{3+}$	Mn^{2+}	$4H_2O$
initial	0.60M	0.10M	1.0M	0	0	0
change	$-5x$	$-x$	$-8x$	$+5x$	$+x$	$+4x$
result	$(0.60-5x)$	$(0.10-x)$	$(1.0-8x)$	$5x$	x	$4x$

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2B$_3$

When reaction is completed Mn^{2+} would have higher concentration, because the huge value of Keq means that higher concentration of product will be formed than the concentration of reactant, given that the coefficients of both Mn^{2+} and MnO_4^- are same.

(f) Using table on the page before,

$$K_{eq} = \frac{5x \cdot x}{(0.60-5x)(0.10-x)(1.0-8x)} = 6.47 \times 10^{60}$$

Solving for x and Calculating for the result would yield the concentrations of Fe^{2+} and Fe^{3+}

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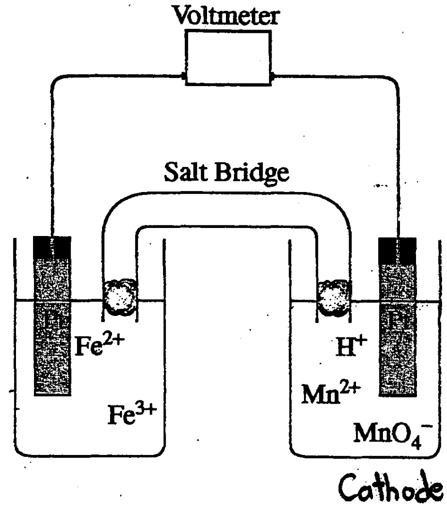
2C1



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(a) On the diagram, clearly label the cathode.

(b) Calculate the value of the standard potential, $E°$, for the spontaneous cell reaction.

(c) How many moles of electrons are transferred when 1.0 mol of $MnO_4^-(aq)$ is consumed in the overall cell reaction?

(d) Calculate the value of the equilibrium constant, K_{eq}, for the cell reaction at 25°C. Explain what the magnitude of K_{eq} tells you about the extent of the reaction.

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(e) When the reaction mixture has come to equilibrium, which species has the higher concentration, $Mn^{2+}(aq)$ or $MnO_4^-(aq)$? Explain.

(f) When the reaction mixture has come to equilibrium, what are the molar concentrations of $Fe^{2+}(aq)$ and $Fe^{3+}(aq)$?

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a. The right half cell is the cathode.

b. $Mn + 8H^+ + 5e^- \longrightarrow Mn^{2+} + 4H_2O(l)$ $\mathcal{E}_{reduction} = 1.49$ Reduction reaction

$Fe^{2+} \longrightarrow Fe^{3+} + e^-$ $\mathcal{E}_{oxidation} = -0.77$

$\mathcal{E}_{reduction} + \mathcal{E}_{oxidation} = 1.49 + (-0.77) = 0.72\,V$

$\mathcal{E}^\circ = 0.72\,V$

c. $1\,mol\ MnO_4^- \times \frac{5\,mol\ e^-}{1\,mol\ MnO_4} = 5\,mol\ e^-$ are transferred

d. $K_{eq} = ?$

$\log K = \frac{nE^\circ}{0.0592}$

$\log K = \frac{(5\,mole^-)(0.72\,V)}{0.0592}$

$\log K_{eq} = 60.8108$

$K_{eq} = 10^{60.8}$

$K_{eq} = 6.31 \times 10^{60}$

The large number of $K_{eq} = 10^{68}$ tells us that the reaction will go into completion.

e. Mn^{2+} will have a higher concentration because the MnO_4^- will be reduced and oxygen would want to go apart from the molecule of MnO_4.

f. $K = 6.31 \times 10^{60} = \frac{[Fe^{3+}]}{[Fe^{2+}]}$ $Fe^{2+} \longrightarrow Fe^{3+} + e^-$

$6.3 \times 10^{60} = \frac{[x]}{[0.6 - x]}$

Question 2

Sample: 2A
Score: 10

This response earned all 10 points: 1 point for part (a), 1 point for part (b), 1 point for part (c), 3 points for part (d), 2 points for part (e), and 2 points for part (f).

Sample: 2B
Score: 7

This response earned 7 of the possible 10 points. In part (e) 1 point was earned for indicating that the Mn^{2+} ion is in excess, with a partial justification addressing the large K_{eq} value; the second point was not earned because the justification does not address the excess Fe^{2+} and H^+ ions. In part (f) the points were not earned because the student does not calculate the concentrations of Fe^{2+} and Fe^{3+} ions.

Sample: 2C
Score: 5

This response earned 5 of the possible 10 points. In part (a) the point was not earned because the student incorrectly indicates that the entire half-cell is the cathode. In part (b) 1 point was earned because the student correctly calculates the $E°$ value. In part (c) 1 point was earned for correctly indicating that 5 moles of electrons were transferred. In part (d) 3 points were earned for the correct calculation of the K_{eq} value and for the explanation that the large value means the reaction goes virtually to completion. In part (e) no points were earned; although the student indicates that the Mn^{2+} ion is in excess, there is no correct justification. In part (f) no points were earned because the student does not calculate the concentrations of Fe^{2+} and Fe^{3+} ions.